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AN APPROACH TO THE REMOTE DETECTION OF EARTH RESOURCES IN SUB-ARID LANDS

by Jean Pouquet

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Greenbelt, Md.

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ABSTRACT

The purpose of these investigations has been to find a better geological tool utilizing the nighttime infrared radiations emitted by the ground, and thereby obtain a better knowledge of the agricultural possibilities of arid and sub-arid lands. The equivalent black body temperatures (T_{BB}) derived from Nimbus II High Resolution Infrared Radiometer (HRIR) in the spectral range 3.5 - 4.2μ (atmospheric window) have been analyzed for all the available orbits from May until mid-November 1966. From this preliminary study certain predominant features emerged and were used as a basis for the interpretation of data. Because only the orbits over cloud free regions were useful, the selection has been made with the aid of facsimile pictures (Figure 1). The grid maps of temperature produced by the computer (Figure 3) have been transformed into maps of isotherms. For the final interpretation only a few examples have been selected for this paper: Figures 5 and 6 summarize the time-history for the two regions finally chosen, Death Valley and surroundings, and Salton Sea - Colorado River region.

The results are shown in Figure 7, an orbit of June 23, 1966 which is particularly representative. The principal results are: detection of tectonic accidents, already known, with emphasis upon the western branch of the San Andreas Fault system; reconstitution of the upper Pleistocene hydrographic patterns showing the link between Saline, Panamint, and Death Valleys, and the Colorado River, and the former courses of this river; recognition of the possibilities of humidity storage which are suggested by areas showing slightly higher nighttime temperatures than expected; close relationships between the agricultural possibilities involved in the preceding statement and the geomorphological stage reached by the different valleys and basins.

The geological usefulness of satellite HRIR measurements has been clearly demonstrated. However, it must be understood that: a) the satellite measurements are no more than a new tool which cannot replace the classical methods used by the geomorphologists; b) the principal value of these measurements lies in the preselection of the sites to be investigated and studied following the old methods, chiefly field work, laboratory analysis and experimentation; c) it would be dangerous to let the non-specialists interpret this information beyond the simple analysis of the temperature patterns. One must keep in mind that the interpretation is valid only when the interpreter is a confirmed specialist of the Earth Sciences.

ZUSAMMENFASSUNG

Zweck dieser Untersuchung war die Prüfung neuartiger Hilfsmittel für die geologische Forschung, wie sie durch nächtliche Messungen der vom Boden emittierten Infrarot-Strahlung durch künstliche Erdsatelliten gegeben sind. Eine bessere Kenntnis der landwirtschaftlichen Möglichkeiten in ariden und semi-ariden Gebieten mag daraus erwachsen. Messungen der Strahlungstemperatur ("äquivalente Schwarzkörper-Temperatur") im atmosphärischen "Fenster" von 3,5 - 4,2μ eines Infrarot-Radiometers hoher Auflösung (HRIR) an Bord des Satelliten Nimbus II für alle Satellitenumläufe im Zeitraum Mai bis Mitte November 1966 wurden untersucht an Hand der vorliegenden Photo-Faksimile Aufzeichnungen. Es wurden für verschiedene Gebiete die Fälle klaren Himmels ausgewählt, die Messwerte mit Hilfe eines Elektronenrechners in Mercator-Projektion in numerischer Form ausgedruckt und Isoplethen-Analysen dieser Daten ausgeführt. Zur geologischen Interpretation wurden nur solche Strukturen verwendet, die sich im Laufe des bearbeiteten Zeitraumes wiederholten. Dadurch wurden atmosphärische (meteorologische) Einflüsse weitgehend eliminiert. In dieser Abhandlung werden dafür nur zwei Beispiele gegeben: Die Abbildungen 5 und 6 stellen Zeitserien für zwei ausgewählte Gebiete, nämlich das Death Valley (Todestal) und Umgebung und die Region Salton Sea - Colorado River, Kalifornien, dar.

Die Folgerungen daraus seien an Abbildung 7 demonstriert, in der die Messungen eines besonders brauchbaren Satellitenumlaufs im Juni 1966 wiedergegeben sind. Die wesentlichen Ergebnisse sind:

1. Das Auffinden (bereits bekannter) tektonischer Phänomene mit besonderer Betonung des westlichen Zweiges des mit der San Andreas Falte zusammenhängenden Verwerfungssystems.
2. Rekonstruktion der hydrographischen Struktur des Oberen Pleistozäns, worin Zusammenhänge zwischen den Tälern Saline, Panamint und Death Valley einerseits und dem Colorado River beziehungsweise früherer Verläufe dieses Flusses andererseits zu erkennen sind. Diese Rekonstruktion wirft neues Licht auf die allgemeine Entwicklungsgeschichte dieses Gebiets.
3. Die Erkundung einer möglichen Speicherung von Bodenfeuchtigkeit, die sich nachts durch etwas höhere Temperaturwerte bemerkbar macht.
4. Enge Zusammenhange zwischen dem geomorphologischen Stadium, in dem sich die verschiedenen Täler und Becken befinden, und den aus Punkt 3 sich ergebenden landwirtschaftlichen Möglichkeiten.

Die Brauchbarkeit von Messungen der emittierten langwelligen Strahlung durch das HRIR-Instrument vom Satelliten aus hat sich klar erwiesen. Es sollte jedoch richtig verstanden werden, dass (a) die Satellitenmessungen lediglich ein neues Hilfsmittel darstellen, das die "klassischen" Mittel des Geomorphologen nicht verdrängen kann, (b) der hauptsächliche Wert dieser Messungen darin liegen wird, Orte von geomorphologischem Interesse zu suchen und auszuwählen, um sie danach mit konventionellen Methoden zu erforschen, hauptsächlich durch Laboratoriums-Analyse und Experiment, (c) es nachteilig wäre, wenn die Verarbeitung dieser neuartigen Informationen, soweit sie mehr als die einfache Analyse der Temperaturfelder betrifft, Nichtspezialisten überlassen bliebe: die Deutung der Messungen kann nur dann von Nutzen sein, wenn der Bearbeiter ein erfahrener Fachmann in den Erdwissenschaften ist.

RESUME

Les travaux dont cette étude fait état ont eu pour but la recherche de nouveaux outils de travail par l'utilisation des radiations infra rouges émises par le sol, la nuit. Une meilleure connaissance des régions arides et sub arides peut ainsi être acquise. Les températures équivalentes à celles qu'aurait un corps noir situé dans les mêmes conditions (T_{BB}) obtenues grâce au radiomètre infra rouge haute résolution (HRIR) transporté par le satellite sont celles correspondant à l'émission dans la bande spectrale 3,5 - 4,2μ (fenêtre atmosphérique). Les valeurs numériques ont été analysées pour toutes les orbites convenables depuis mai jusqu'à la mi-novembre 1966 afin d'observer l'évolution dans le temps et éliminer ce qui n'est qu'accidentel. La sélection des orbites a été opérée par l'examen des fac-simile (Fig. 1) afin de ne conserver que celles correspondant à des cieux sans nuages au-dessus des régions étudiées. Les documents réalisés à l'aide d'ordinateurs (Fig. 3) ont été transformés en cartes d'isothermes. Pour les besoins de cette étude on n'a conservé que quelques exemples caractéristiques, et, finalement, deux régions, celle de la Vallée de la Mort et environs, et celle de Salton Sea - Colorado sont proposées à l'attention du lecteur (Fig. 5 et Fig. 6).

Les résultats reportés sur la carte Fig. 7 correspondent à une orbite particuliérement démonstrative (23 juin 1966); les principaux sont:

1. Détection d'accidents tectoniques, déjà connus, l'accent étant mis sur la branche occidentale du système de la faille San Andreas.
2. Reconstitution du système hydrographique de la fin du Pléistocéne, montrant les liens entre les vallées de la Mort, Panamint, Saline avec le Colorado ainsi que les anciens cours de cette dernière rivière. Cette reconstitution enrichit nos connaissances sur l'évolution générale de la région.
3. Reconnaissance des possibilités de rétention d'humidité laquelle, pendant la nuit, est détectée par des températures légèrement plus élevées.
4. Relations étroites entre les possibilités agricoles évoquées ci-dessus et le stage géomorphologique atteint par les différents bassins ou vallées (Fig. 9).

L'utilité des radiations infra rouges émises par le sol et retransmises par le satellite est parfaitement claire. Cependant, il doit être bien entendu que: a) les mesures transmises par le satellite n'offrent rien de plus qu'un nouveau moyen de recherches qui ne peut être substitué aux anciennes méthodes; b) leur principal intérêt réside dans la présélection des sites à étudier selon les méthodes classiques, notamment, travail de terrain, analyses et experiences de laboratoire; c) il serait dangereux de laisser les non spécialistes aller au delà de l'analyse préliminaire des documents réalisés dont l'interprétation requiert les connaissances du specialiste des sciences de la terre.

CONTENTS

AN APPROACH TO THE REMOTE DETECTION OF EARTH RESOURCES IN SUB-ARID LANDS*

Terrestrial Features in the Southwest United States Derived from NIMBUS II Measurements (High Resolution Infrared Radiometer) with Field Control.

by

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INTRODUCTION

A geomorphologist spends most of his time in the field, looking at maps and aerial photographs. Yet the results obtained after many years cover relatively small areas. Our research could be eased and improved if, in advance, we knew not only where to go, but the principal problems we should try to resolve and if, instead of a small acreage, we could study an extensive area covering many square kilometers in order to replace in their own context the detailed features studied.

The increased use of aerial photographs has indeed improved our knowledge. Extensive work in the laboratory has substituted some numerical data for the qualitative appreciations that were the rule until recently. However, the geomorphologist is still restricted to the study of relatively small areas similar in size to an American County or a French Department. Furthermore, even the aerial photographs do not provide new data; because of their scale, around 1:20,000, and because they register only the reflected light.

Satellites offer new possibilities, being able to scan wide areas with an acceptable angle of view that permits the study of fine terrestrial details. In addition, the emitted infrared radiation of the ground received and transmitted by the satellites can be referred to the temperature of a black body, so that we can obtain, instead of the "outside" of the terrestrial features, what we might call their "signature"—a numerical means of recognition.

My goal has been simple. Because I was familiar with the regions chosen for the present investigations, I checked what I had previously studied in the recent past using the classical methods, employing maps, results of field work, aerial photographs (References 1 and 2). For the present purpose, I selected all of the available orbits of Nimbus II, showing cloudfree sky over the Southwest United States. The orbits have been carefully scrutinized; twenty of them have been completely mapped at the 1:1,000,000 scale (grid-print maps, computer-produced). Only a few are presented in this paper, enough to show the time-history of the events being studied. Only the features seen on all the orbits have been taken into consideration.

*Paper presented to the International Congress of Geology 21 August 1968, Section XIII, Prague, Czechoslovakia.

[†]On leave from the University of Aix-Marseille, France, as a National Academy of Sciences - National Research Council, Senior Postdoctoral Resident Research Associate with the National Aeronautics and Space Administration.

Previously known facts have been confirmed by this new approach. Many new features have been detected through the satellite measurements and subsequently checked in the field. In so doing not only has it been possible to check the infrared results, but also to complete these investigations over parts of the ground that were overwhelmed by the surrounding. It is clear that the High Resolution Infrared Radiometer carried by the satellite appears as a new tool in geomorphology, a particularly powerful one, that organizes, leads, and enlarges our research, yet is not a substitute for the former methods of approach and cannot replace imperative field work.

TECHNICAL ASPECTS

Nimbus II was launched on 15 May 1966 in a nearly sun-synchronous orbit, the apogee height being 1179 km and the perigee 1095 km. When northbound, the satellite crosses the equator near midday; when southbound, near midnight. Within a 24-hour period, every portion of the earth is scanned at least once by day and once by night.

Among the equipment aboard (Reference 3) Television cameras, Medium Resolution Infrared Radiometer (MRIR) and High Resolution Infrared Radiometer (HRIR) we are interested only in the latest, and in particular in the measurements obtained during the night (References 4 and 5). The HRIR equipment worked perfectly until 15 November 1966 when, during the interrogation of the orbit 2455, the tape recorder aboard Nimbus II malfunctioned, terminating the availability of HRIR data (Reference 3).

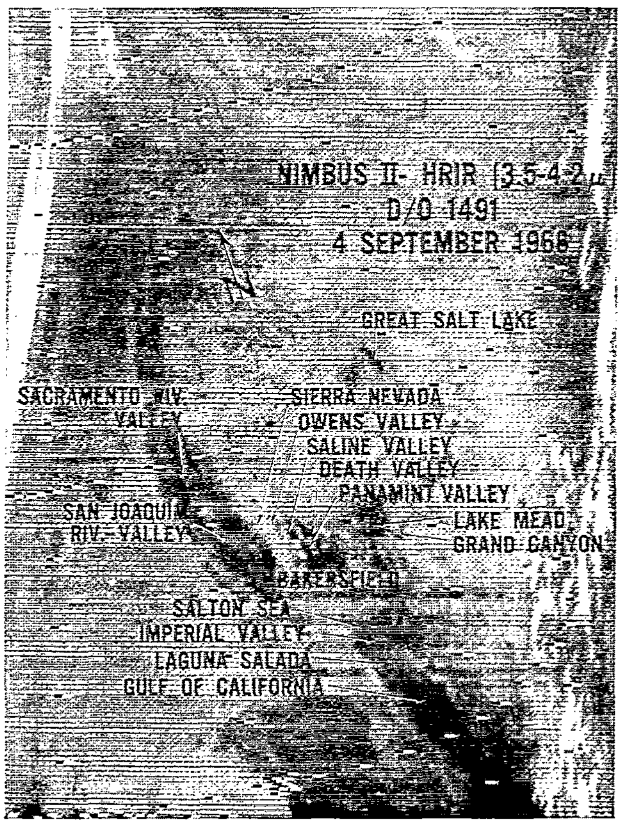


Figure 1—Facsimile Nimbus II HRIR, orbit 1491, 4 September 1966.

The HRIR data received from the satellite, after several operations, are converted into facsimile identified by the GMT time, number of the orbit, and superimposed coordinates. Figure 1 shows an example of such a facsimile in which the dark tones correspond to higher equivalent black-body temperatures, T_{BB}, and the white ones, showing very low T_{BB} values, depict the clouds. Despite the gray scale calibration accompanying the facsimile, it would be dangerous, if not quite impossible, to reconstruct the temperatures in degrees Kelvin.

"A much more quantitative picture results when the original analog signals are digitized with full fidelity and the digital data are processed by . . . a computer where calibration and geographic referencing is applied automatically" (Reference 6, page 28). A grid print map is made in which, at the scale of 1:1,000,000, the numerical data are printed every 12 km or so. It is now possible to draw the isotherms and so obtain a general pattern of the distribution of the ground temperatures.

Most of the time, instrumentally introduced noises perturb the temperature pattern: Figure 2 shows a good example of such disturbance exactly ranged along a single scan. In such a case it is easy to neglect the superimposed signals. More often, noises are difficult to detect unless a filter is used. Furthermore, instead of data printed only at the crosses of the mesh (8 crosses per degree) the computer can be programmed for "contouring," i.e., filling with figures or letters all the areas where the temperatures are between (for example) 280 and 289°K (filled with 2's), then between 260 and 269°K (filled with 1's); between 300 and 309°K (filled with 3's), etc. . . . Most of the maps studied for these investigations have been realized with such a contouring every 10°K, but without the filter which has since been designed by Larry McMillin.

Later, filtered data and contouring every 2° was requested. Figure 3 shows such an example where the following letters signify areas with the following respective temperature ranges: C, 292-293°K; D, 296°-297°; E, 300°-301°; F, 304°-305°, etc. ... The isotherms are already practically drawn; furthermore, with such a contouring every 2°K, the precision approaches that of the High Resolution Radiometer.

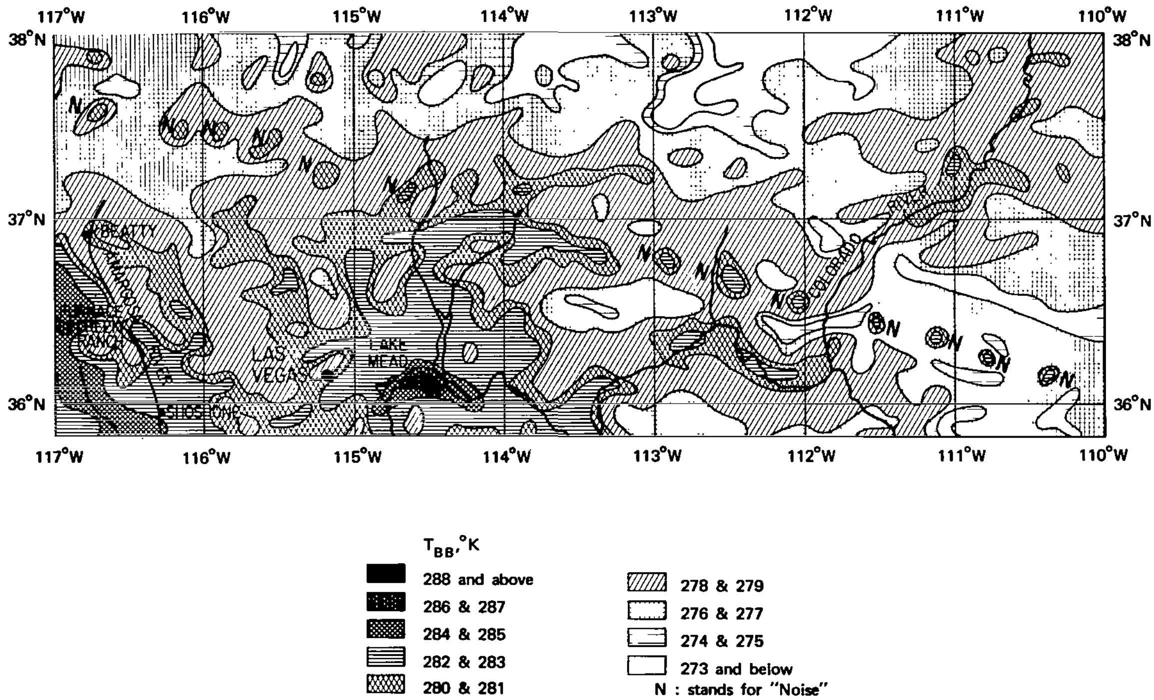


Figure 2—Instrumentally introduced noise (isotherms map), Nimbus II HRIR, orbit 2423, 13 November 1966.

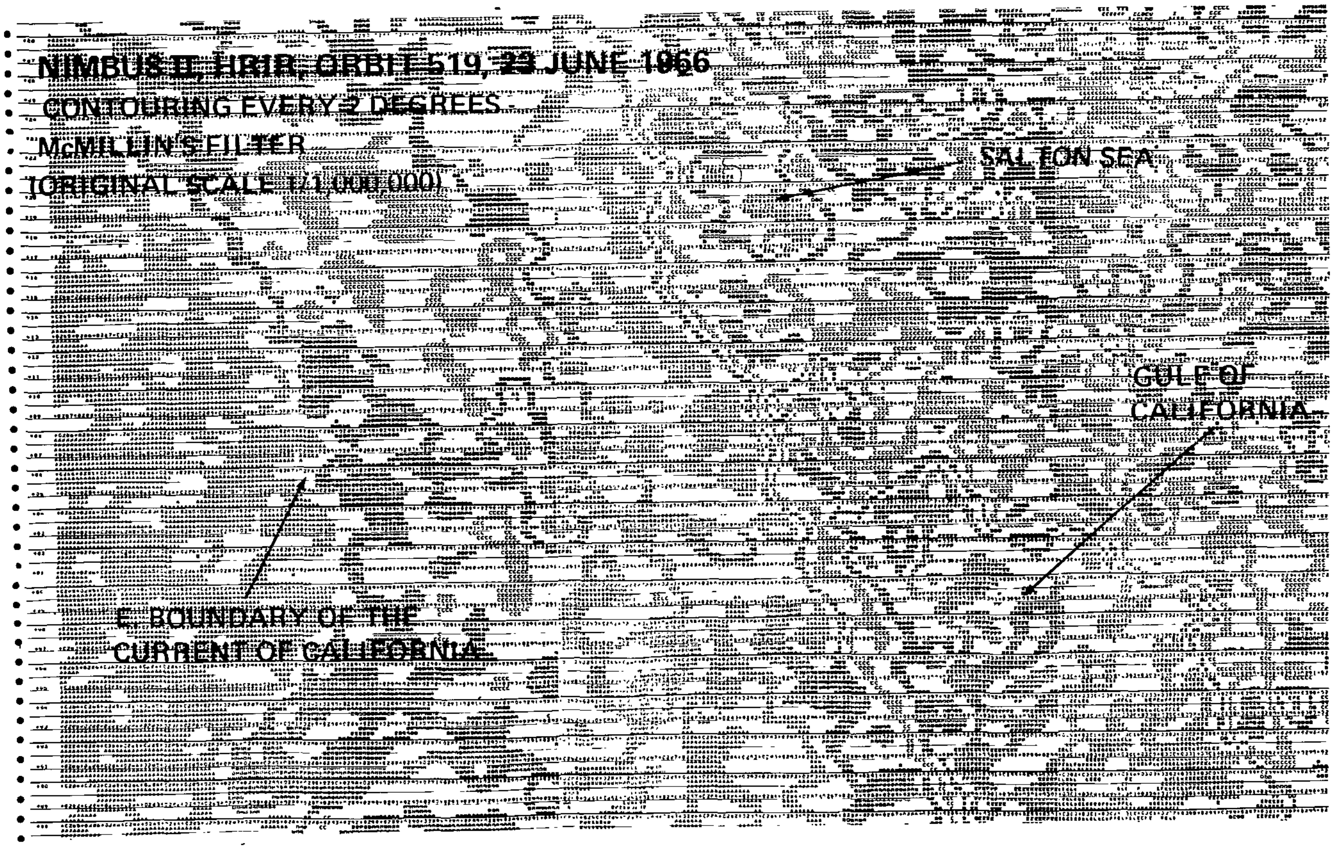


Figure 3—Computer-produced grid-print map, Nimbus II HRIR, orbit 519, 23 June 1966, filtered data contouring every 2 degrees.

The accuracy of the infrared measurements has already been stated (References 7, 8, 9, 10, and 11). The cross sections (Figure 4) illustrate the fidelity with which the ground temperatures reflect the altitude. This "fidelity" should be considered with the greatest care. Indeed, if the elevation of the ground features was the only explanation for the temperature differences, we would not need such an instrument for our studies. Actually, the deviations from the altimetric rule* are generalized, a given area being either warmer or cooler than it should be. These deviations provide the "key" for a better understanding of the temperature pattern, because they are the consequence of differences in rock formations, in moisture content and in the degree of weathering.† For example, Death Valley and Panamint Valley are cooler than was expected when compared with the Sierra Nevada; by the same token, Saline Valley is warmer. The answers to the numerous questions so raised are the goals I have been looking for. They are also the best leads to a better knowledge of the earth we live on, to a better utilization of the land, and, hence, are the best answers to world preoccupations concerning the earth's resources.

*i.e., an average decrease of 5 to 10 °K per 1000 meters of higher elevation following the adiabatic circulation, either dry (10 °/1000 m) or wet (5 °/1000 m).

†These investigations might be considerably eased if the computer could derive temperatures reduced to the sea level instead of the raw ones.

EQUIVALENT BLACK-BODY TEMPERATURE PATTERNS

Only a few of the maps actually drawn are described in this essay, since all of them show the same data. Furthermore, this study is restricted to those areas observed on a subsequent field trip, which can be divided in two regions: (1) the Coachella Basin and surroundings (Figure 5), (2) the Death Valley - Sierra Nevada region (Figure 6).

Coachella Basin and Surroundings

From May to November, the warm and cool areas coincide. Among them, the hot temperatures of Salton Sea - Imperial Valley, of the environs of the Colorado River, and of Laguna Salada are particularly striking, but with modifications in absolute values and contrasts from May to November, the tendency being a general "smoothing" after the peak of Summer. This tendency is summarized for July (Figure 5A), September (Figure 5B) and November (Figure 5C). In July the hottest spot is linked to the Colorado, just north of 33°N, with 302°K. The Salton Sea proper and the Laguna Salada reach 300°K; Yuma only reaches 294°K. More interesting is the long row of steep gradient (296 - 286°K) striking N.NW-S.SE, west of the Gulf of California to the neighborhood of Palm Springs.

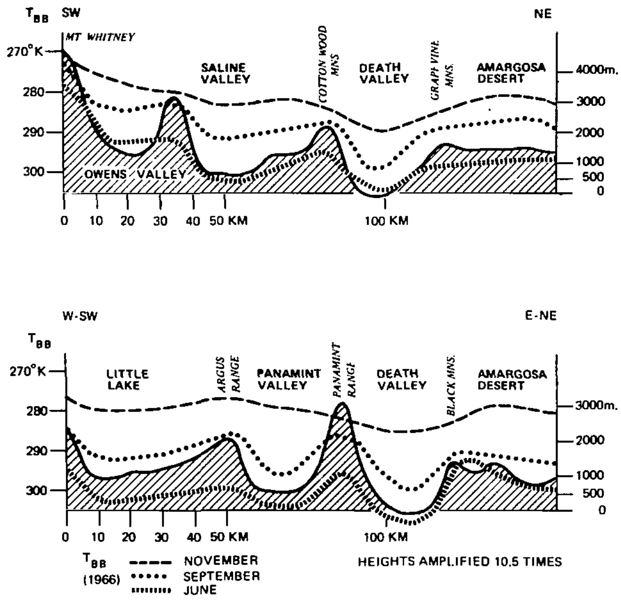


Figure 4—Cross sections (topographical and thermal) across Death Valley and other features.

For September (Figure 5B) the contrasts are similar: 300°K instead of 302°, 300° (no change), 298° instead of 300°, 296° instead of 294°; and finally, the tight gradient is 8° instead of 10°. In November, this tight gradient has almost completely disappeared, the vicinity of Yuma is at 282°K, the Laguna Salada 284°, Salton Sea 292° and the warmer spot along the Colorado at 286°. In July, the maximum difference for the areas cited, with the exception of the "row," was 8°K; 4° in September; and 10° in November if the exceptionally warm Salton Sea is included, 2° if it is excluded.

It has been necessary to exclude from consideration the sea coast and a great part of the continent inland because of the continuous veil of haze almost invisible to the naked eye. This hazy obstacle is present throughout the nights of summer. The ground visibility is still reasonably good but the infrared radiations are obscured. As one can easily see when looking at the facsimile, the contact between land and ocean in California is never sharp, always blurred or invisible.

A first conclusion can be drawn from these remarks: the sharpest contrasts in that part of the world are observed during the hot and dry summer. Consequently, the features we are looking at are easier to detect, and hence to analyze and interpret, during the months of June through September. The same impression is given by the cross sections of the Death Valley region (Figure 4).

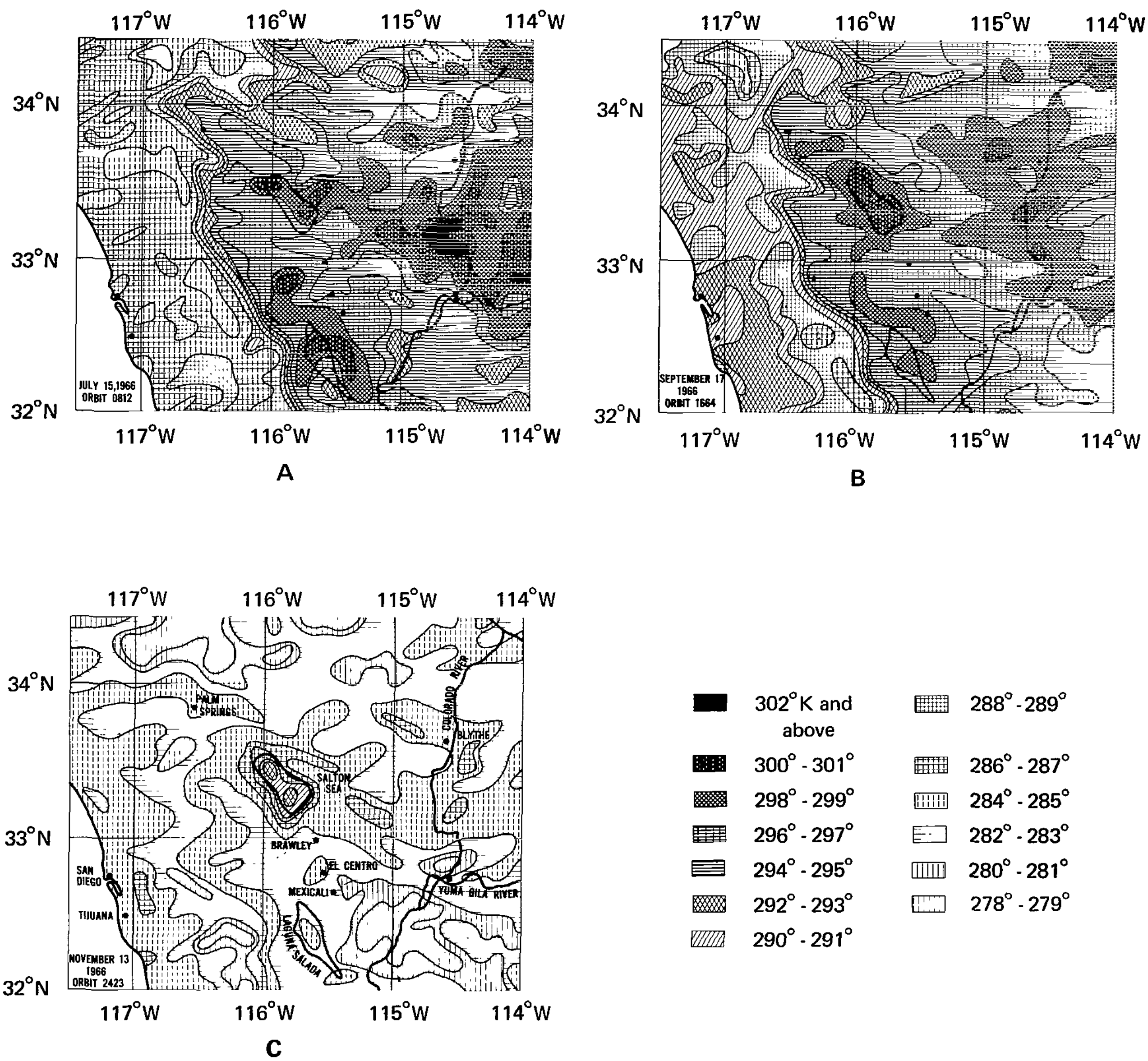


Figure 5—Evolution of the ground T_{BB}, region of Coachella Basin, 15 July, 17 December, and 13 November 1966.

Death Valley Region

Similar observations can be made about this region. It is obvious that such features as Death Valley, Saline Valley, and part of Panamint Valley show up as very hot areas (but not as hot as most of them should be); by contrast, it is not surprising that the Sierra Nevada and mountains such as the Panamint Range, Inyo Mountains, etc. should be very cold, with temperatures as low as 274°K (1°C) in September for the vicinity of Mount Whitney, 276°K in July (3°C), and 272°K in November (-1°C). Despite its size (at least on the maps), Owens Lake is "lost" within the surroundings. In fact, what is left of the former lake is not wide enough for the resolution of the radiometer and cannot be

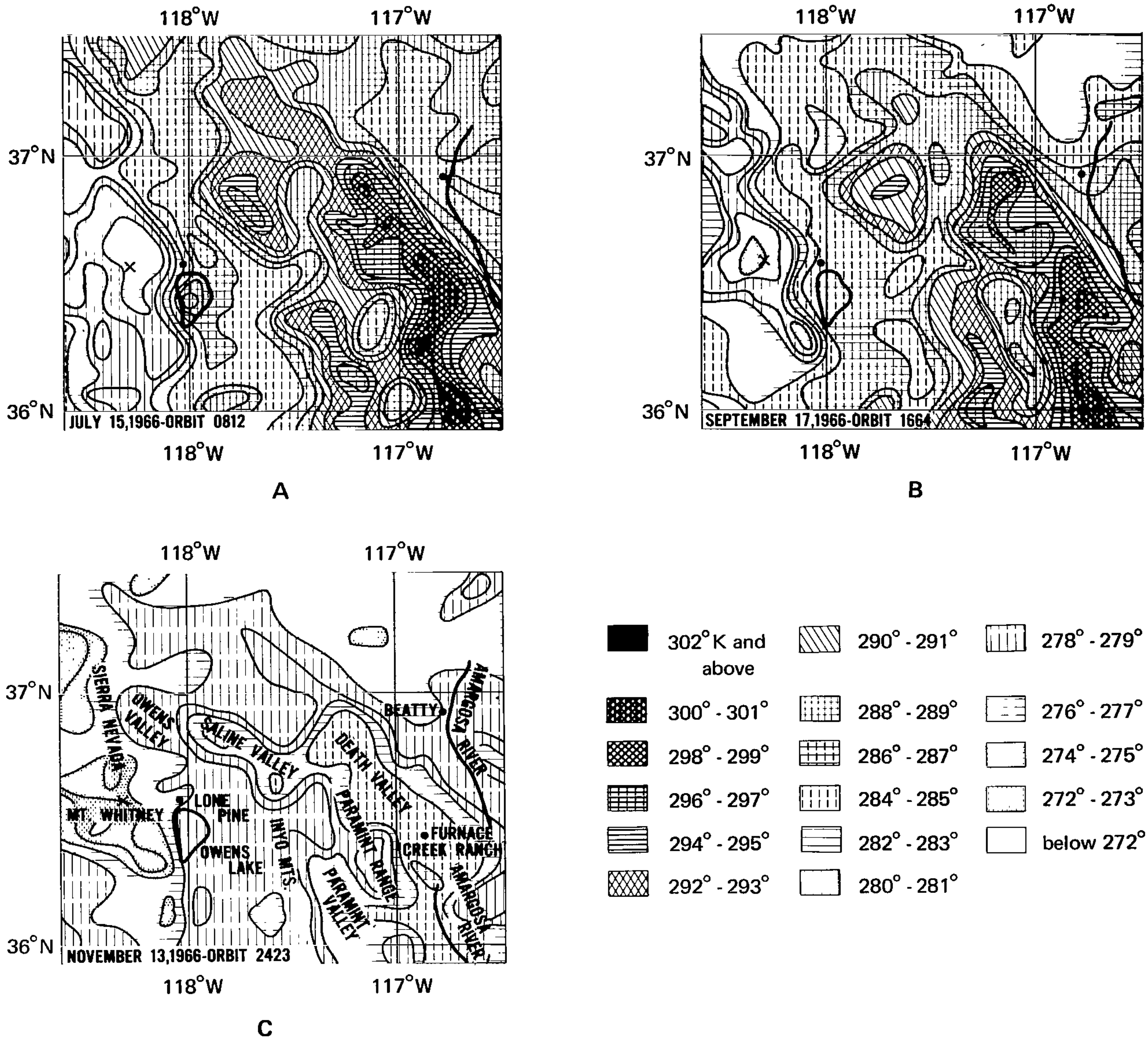


Figure 6—Evolution of the ground T_{BB}, Death Valley - Sierra Nevada region, 15 July, 17 September, and 13 November 1966.

individualized through the emitted infrared radiations. Only one exception exists throughout the period May-November 1966—in July (Figure 6A), with a narrow spot at 288°K. (Apparently this is a case of instrumentally introduced noise.) Table 1 emphasizes some of the problems arising from this short analysis of the temperature patterns.

The first problem is straightforward: why are Death Valley, Panamint Valley and the northern part of the Coachella Basin cooler than expected? Similarly, why should Saline Valley, Imperial Valley and Laguna Salada be warmer than expected?

Table 1

Thermal Gradients Between Nearby Topographical Features.

Topographical Features	Difference in Elevation (m)	Maximum and Minimum Gradients With Respect to a Wet or Dry Adiabitic (°K)	Actual Thermal Gradients (°K)						Observations
			June	July	Aug.	Sept.	Oct.	Nov.	
Owens - Saline Valleys	700	7 and 3	6	8	10	10	8	6	Saline Valley warmer than expected
Panamint Valley - Panamint Range	2500	25 and 12	6	10	8	8	4	4	Panamint Valley cooler than expected
Death Valley - Panamint Range	3500	35 and 17	8	14	12	14	10	8	Death Valley cooler than expected
Lowest and Highest Parts of Death Valley	700	7 and 3	4	8	6	6	6	6	Northern part slightly warmer than expected (region of Ubehebe crater)
Death Valley - John Muir Ridge	4500	45 and 23	21	24	22	28	20	14	Death Valley cooler than expected
Coachella Region - Imperial Valley	90	1 and 0.4	2	2	0.5	2	4	1.5	Imperial Valley warmer than expected
Coachella Basin - Western Ridge	1400	14 and 7	6	8	4	8	4	4	Coachella Basin cooler than expected
Laguna Salada - Western Ridge	600	6 and 3	8	12	—	8	8	6	Floor of the ancient lake warmer than expected

These are not the only questions raised; Figure 7 points to further, important considerations. It is particularly surprising to observe long rows, usually irregular, of warmer strips of land: for example between the Amargosa River and the region of Amboy· or the several strips linking the Colorado River to the region of Desert Center; also (through different routes between the Colorado at Needles, Blythe, and Vidal Junction to the close vicinity of Salton Sea) warmer areas not explained by the altimetric position. Finally, there is a wide cool area between Tucson and the Mexican Border despite the well-known prosperity of that region, characterized, among other things, by prosperous Indian settlements and the growing center recently created, of Green Valley; a region drained by the Santa Cruz river and distinguished by the humidity of its soil, which should show up as a warmer are

INTERPRETATION

Preliminary Remarks

I would like to recall some simple facts before trying to answer the preceding questions. The approach is exactly the same as that used with detailed maps and aerial photographs: one reads

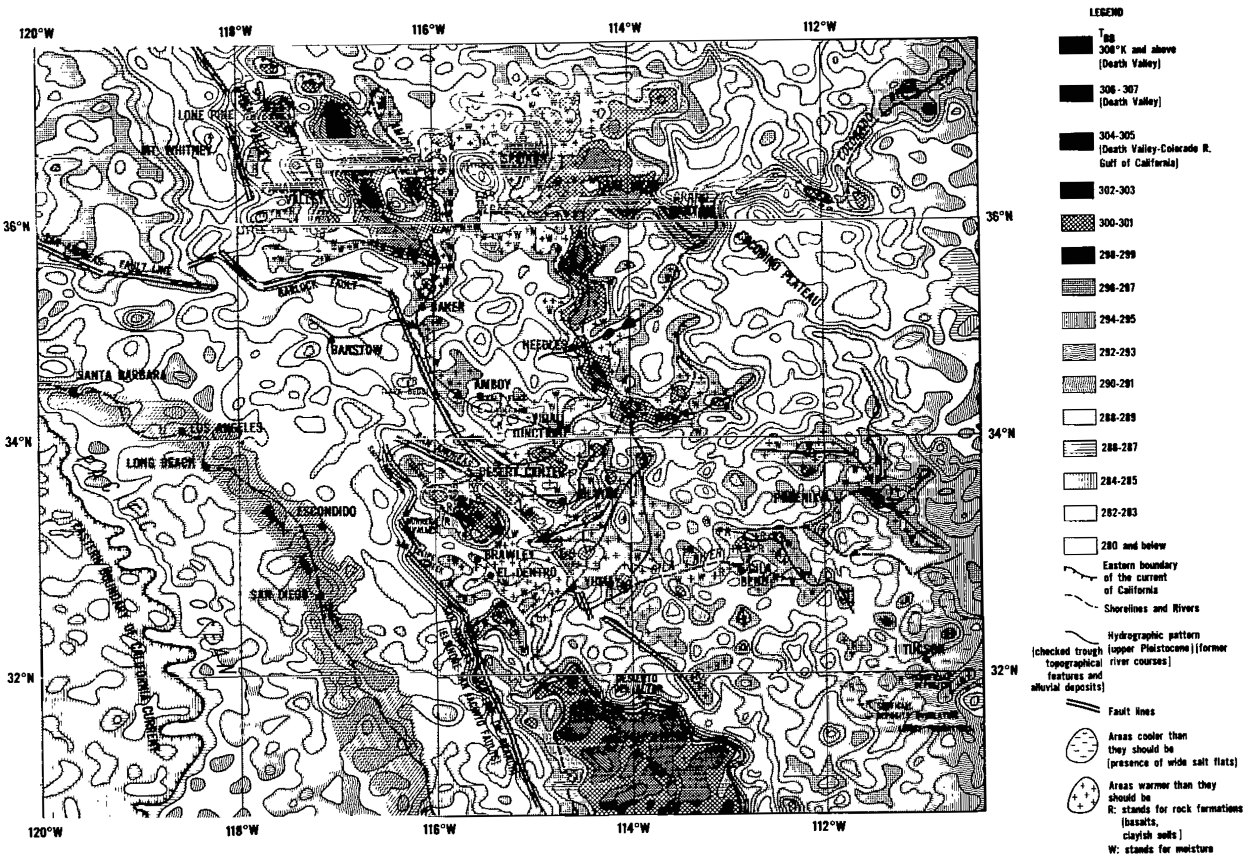


Figure 7—Terrestrial features derived from Nimbus II nighttime measurements and field control, orbit 519, 23 June 1966.

the documents; then analyzes them. The latter process consists of gathering similar facts, organizing them, and depicting the problems. We have just accomplished these two indispensable studies, which should *not be confused with interpretation.* Such an interpretation, the real goal of any investigation, *requires a specialized background* in geology, geomorphology and geopedology. Furthermore, the specialized background alone is not sufficient: the problems raised by the analysis have to be checked in the field with what one might call the "classical tools"—direct observation, sampling, reasoning. For this purpose, I returned to the field and, as previously stated, not only were the preliminary interpretations confirmed, but new facts came to light, notably those concerning the former courses of the Colorado and Amargosa Rivers (References 1 and 2) and the link that existed until the recent past between the Saline and the Panamint Valleys and which is now completely obliterated.

Among the "background" knowledge that has been used, I must recall the considerable role played by undisturbed alluvial deposits and water movements through geological features.

Role of Undisturbed Alluvial Deposits

When alluvial, the particles are organized, disposed after the direction, velocity, and nature of the responsible streams; this condition is usually recognizable with the naked eye because of the bedding and the roundness of the sand particles and pebbles; also, without this evidence, the condition is easy to detect with the help of a sedimentologic analysis. Such alluvial masses, when undisturbed, form a natural route followed by the water, even when the responsible river has disappeared or shifted its bed. In such a case, dew, rain, or flood find a safe place to be stored. The volume of wasted water is minimized to the extreme limits. Moreover, the quantity of stored water is maintained for a longer time than in unorganized (or disorganized) debris, as often demonstrated by several specialists. One sees immediately the advantage of such knowledge: when the land is ploughed and devoted to agriculture, the amount of additional water required for irrigation purposes in arid and sub-arid lands will be minimal because of the absence of excess evaporation and of the longer time the moisture will be retained within the alluvial mass.

These facts are valid only when the primitive alluvial disposition still exists. When this disposition is disturbed, for example by the processes of rejuvenation (increasing erosion), numerous "scars" are inflicted on the soils that cannot store the humidity needed for agricultural activities.

Movements of Soil Moisture (References 3 and 4)

During the heat of the day, the upper horizon of the soil becomes increasingly dry; the moisture is driven downward, toward the cooler part of the soil profile. The surface does not reveal possible humidity underneath; everything else being equal, there is a tendency to uniformization.

At night, the surface cools rapidly, the inverse processes are observed, and the moisture, in rising, brings with it a part of the heat stored during the day. As a consequence, anytime that during the night an area is warmer than expected following its topographic position, one must look for either the geologic features (rock formation, tectonic accident) or for humidity. Often it is possible to foresee the real cause with good geological and topographical maps or with the help of aerial photographs; sometimes the solution may only be surmised; in any case, it is dangerous to jump to conclusions without a field control.

Geological Features

It is obvious that two different rock formations have different heat capacities; and that, mainly at night, the rocks able to store more and for a longer time the solar heat, will show up as warm areas. But, I do not believe that we can recognize rocks with "spatial media," even using spectrographic data, with the exception of two big categories, acid and basic rocks, for example limestone (basic) as opposed to most of the granites (acid). What I stated about The Northeast Sahara in Reference 3 was possible because of personal knowledge of several areas and because of topographical and geological maps giving the necessary clues, concerning "weathered" and "unweathered" sands, the former being warmer at night.

That paper deals chiefly with the long fractures known as faults. Everybody knows that a fault makes a path for migrating waters. In other words, when such an accident exists and moisture is available nearby, the humidity has a tendency to accumulate along the geologic fractures, bringing at night, as already stated, the warmth of the day that has been stored in the lower layers. Furthermore, the foot of the topographical accidents duplicating such faults, is often composed of loose material, mostly fans, aprons, of alluvial origin.

These places are known for their ability to store water and moisture, and they show up, on the digitized maps and the facsimile, as warm areas, with geometrical shape, usually long strips following the strike of the faults. A good example is to be seen west of the Coachella depression. Sometimes the topography can explain the sharp contrast between cold and warm "ribbons," but more often the difference in elevation is not enough to provide this explanation.

Results

Figure 7 summarizes the results which can be grouped into four categories, tectonic features, rock formations, soil moisture content, and former hydrography.

Tectonic Features (Figures 5, 6, 7, and 8)

All the aligned steep gradients, following a straight line, are linked to tectonic accidents of varying complexity. With a few exceptions these faults are young, rejuvenated, hence, the tectonic escarpments are emphasized by steep, almost vertical scarps. The best examples are seen along the western border of Saline Valley, the eastern border of Death Valley, and on either side of the Coachella Basin stretching southward to the Mexican Border.

On the eastern side of the Coachella Basin, the line of the accident is somewhat hypothetical (Figures 5A and B), but we know that the prolongation of the San Andreas Fault Line follows precisely the line of contact between the 298° and 296°K isotherms (Figure 5A). On the western fringe the contrast is sharper and the fault line is followed northward to the vicinity of Palm Springs. The two faults, east and west of the Basin, delimit exactly the subsiding trough, of which a part is already below sea level and whose lowest part has been occupied by Salton Sea since the beginning of the century; before the momentary diversion of the Colorado, this trough was known as Salton Sink. It is my opinion that the San Andreas Fault actually is split in two branches with numerous horizontal shiftings, the main branch being not on the eastern side of the basin, but on the western.

The case of Saline Valley deserves supplementary explanations. This tectonic graben has an oblong shape, striking NW-SE. The Valley shows up on the temperature maps, either as a hot area duplicating the topographical shape of the Basin (Figures 6A and C), or with a bulge to the NE as seen on Figure 6B, partly on Figure 7. That occasional outgrowth is surprising in such topographical conditions. This is why, with the help of a Ranger of the National Monument of Death Valley, I took the risk of getting in that basin at a time of the year (winter) positively not in favor of such an expedition.

The Saline Valley graben is a typical "text book" example of such tectonic features. The western side is still under tectonic activity, the floor collapsing, leaving vertical escarpments with

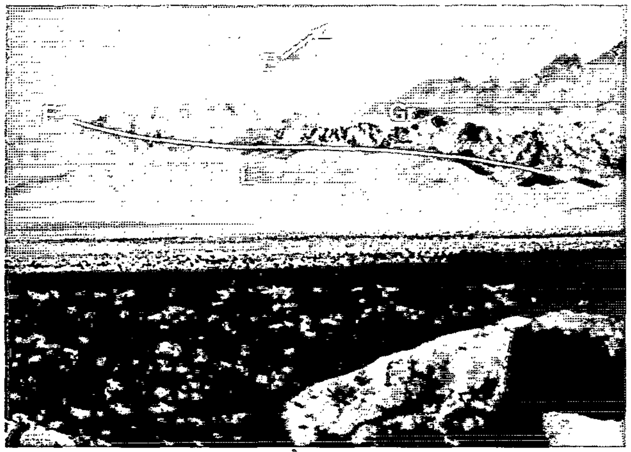


Figure 8—Saline Valley, eastern border. (Gr: granitic formations; L: paleozoic, limestone formations; F: fault line.)

vestiges of former but recent overhanging fans. One can observe that the Equivalent Black Body Temperatures throughout Nimbus II observations are distributed following the same pattern along this western fringe, in sharp contrast with the eastern border.

Along this eastern border, the slopes are not so steep; some small rivers have already dug their valleys. Furthermore, the tectonic features, instead of striking NW-SE, are oriented SE-NW (Figure 8). The faults are older. The fans, at the foot of the cliffs, are bigger than on the opposite side. Some fault lines are already followed by rivers taking advantage of the weakness always linked to contacts between different rock formations, and chiefly along such accidents. Figure 9 summarizes these observations, and consequently provides the explanations we are looking for.*

The eastern side of Saline Valley being older, tectonically speaking, the running waters have had time to start the usual work of rivers, deepening and widening their valleys, spreading alluviums, tracing the route to be followed by underground waters regardless of their origin. Older and also too young—such are the qualitatives to be used when speaking of that part of Saline Valley. Too young means that the seepage of rain, flood, dew, . . . continues only temporarily. In simpler words: the effect of a rain is felt immediately after the precipitation as everywhere else, but not for so long a time as in a real old valley. The alluvial deposits are too thin; they are only moistened, and they dry almost as quickly as barren rocks; furthermore, there are no underground streams, and no moisture movements longer than a few days in duration. In consequence, after a rain or after the melting of the snow, the geological features of the eastern side are able to keep a part of the moisture which distinguishes them. Within a short time, the alluviums and rocks are drained and, only a few days after the rain, no longer produce a "surplus" of infrared radiations; now, the topographical shape of the basin overwhelms any other cause.

Rock Formations (Figure 7)

The humidity of the soil is not the cause of the temperature values of Death Valley and Panamint Valley, despite the certain presence of water near the surface. The Owens Lake region is not warmer than its immediate surroundings. To the south of Owens Lake, lies the region of Little

*A comparison between Saline Valley and the median part of Death Valley is self-imposed (Reference 1). Both are recent collapsed basins. Both offer identical opposition between western and eastern walls, between the size of fans or aprons. It must be said that the sides are reversed: in Saline Valley, the western side is still under tectonic stress, while, in the median part of Death Valley, the eastern side knows these activities at the present time. It is my belief that the trough of Death Valley is older than Saline Valley where all the tectonic accidents look really fresh, as if this revolution had just began.

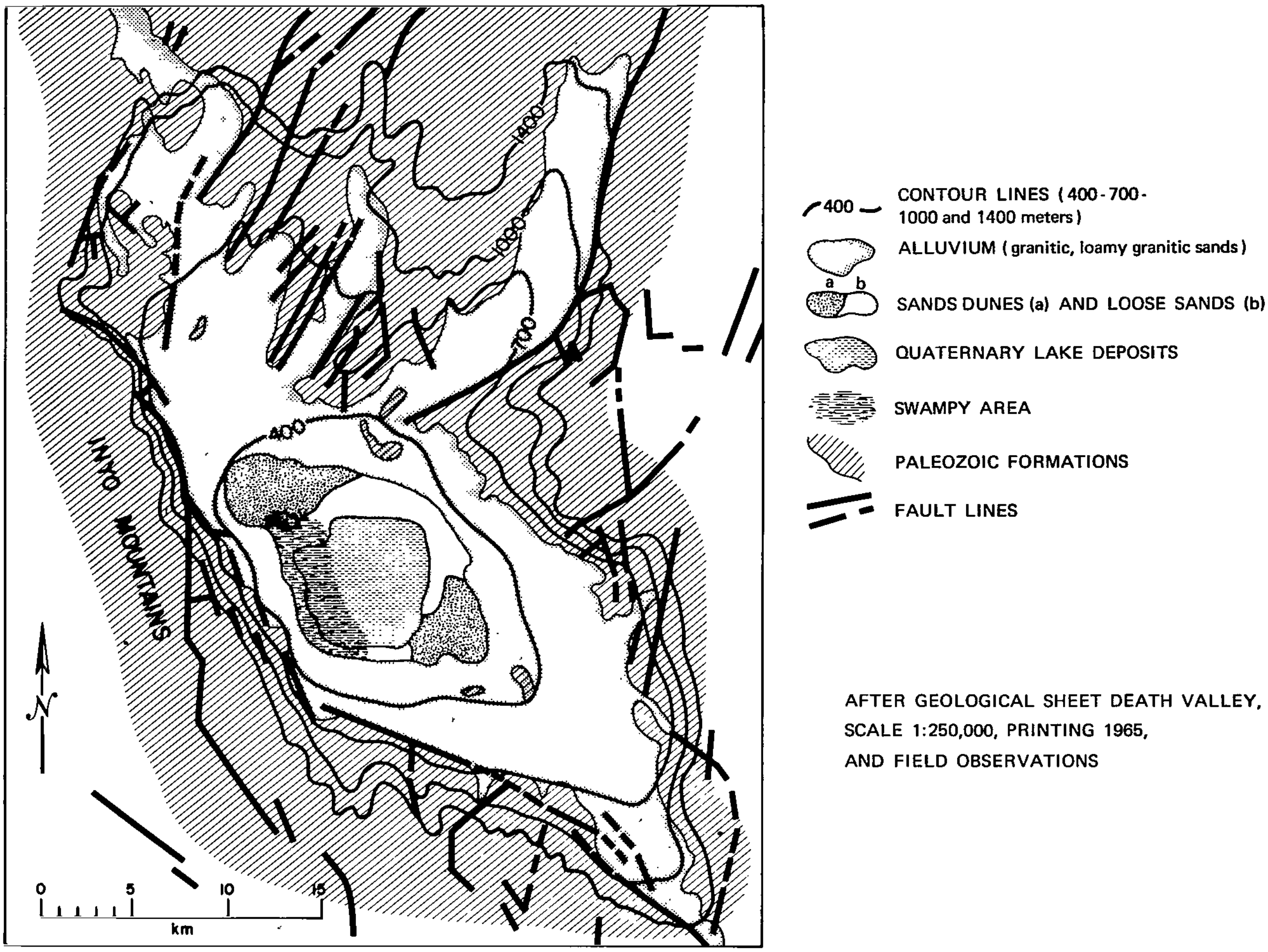


Figure 9—Main geological features of Saline Valley.

Lake which is warmer than expected; but the water is not responsible, despite the presence of a lake that is too small to influence the infrared radiations in respect to the resolution of the radiometer. These four examples reflect the influence of rock formations. Death Valley, Panamint Valley, and Owens Lake region owe their lower night temperatures to the widespread salt deposits whose albedo is great, hence their heat capacity is low (References 3, 4, and 12). As for the Little Lake area, the slightly higher temperature is the consequence of widespread recent lava flows, (mainly basaltic) and of fresh volcanic features (plug volcanoes, cinder cones) (References 13 and 14). The same observation is applicable to the Ubehebe Crater region in the northern part of the National Monument of Death Valley, which is slightly warmer than its position would allow with respect to the main part of the basin: in that case the mantle of fresh volcanic ash or basaltic fragments provides the explanation.

I do not think it is possible to identify rock formations through the equivalent black-body temperatures. The infrared radiations can only attract the attention of the scientist, inviting him to pay a visit to the field. Besides, even the bodies of water can lead to a wrong conclusion, because the water may not only fail to absorb the infrared radiations but may act as a reflective surface, probably because of biological factors (Reference 15), and it is my belief that the lower temperature of Death Valley may stem from this cause, at least for that swampy area of the basin known as the Devil's Golf Course.

Soil Moisture

The preceding explanation might be applied to the region of Amboy Lake (a dry lake), the cool sector linked to the widespread salt formations overwhelming the influence of the recent volcanic formations. On the other hand, the warmer areas to be seen all along the highway between Yuma and Phoenix, particularly around Gila Bend, may be due to widespread volcanic formations. This statement is no more than a suggestion; the bad weather I met while working in that area prevented me from leaving the highways.

Of greater interest are all these "warmer than expected" areas, Saline Valley, Laguna Salada, and the strips linking the Colorado River with adjacent places. In every case, soil moisture provides the explanation, with nuances.

The cases of Saline Valley and Laguna Salada are the simplest. The mantle of alluviums covering their floors is composed of fine debris whose salt content is not sufficient to increase the reflectance of this material. As usual, the daylight solar energy is stored within the deposits. There is enough moisture to carry upward, during the night, a part of this heat.

Unfortunately, it was not possible to check this theory in the field, in respect to Laguna Salada, in Mexico. For the Saline Valley, the facts are clear. With the exception of the lowest part of the basin where small salt flats are seen along with a little pool, the floor is made of granitic sands already weathered. Because of the structural configuration of the trough, the seeping waters converge toward the center part of the basin, through the alluviums. At the northern end of Saline Valley, Sand dunes owe their existence to the proximity of the water table as in Death Valley (Reference 1).

These features are readily detected. Different, and more valuable, is the case of the "divergences" of the Colorado River (Figure 7). These irregularly shaped strips of warm areas are the result of a general widespread moisture. Along these paths, beneath the surface of the soil, the water circulates through the alluviums. The origin of this water is multiple. One source is the Colorado River, mainly at the time of high waters, because of the infiltration through its banks into the former deposits. That part follows the old routes of the rivers, underneath, and almost reaches the eastern margin of the Coachella Basin. With elapsing time, the amount of subterranean water decreases, the maximum occuring just in late winter-early spring; it is still appreciable during the summer, falling to a minimum in October-November.

These "hidden" waters are also fed by the winter precipitations and by occasional cloudbursts in summer. In my opinion, the result is a permanent supply of water available throughout the year. More important is the possibility for these alluvial formations to retain the waters, regardless of their origin.

I do not think there is enough humidity naturally stored in the soil to permit agricultural activities, but I do believe that the necessary watering would require a minimum of irrigation, because the wastage by evaporation and runoff would be minimal. It is my strong belief that numerous "Imperial Valleys" might come into existence, readily, as did "the" Imperial Valley, California, not so long ago. Most of the empty lands between the Colorado River and Salton Sea could be drastically changed, converted into luxurious gardens.

The same reasoning, exactly reversed, is applied to the region from Tucson south to Nogales. This part of Arizona is cooler than it should be, with only one "window" (word used on purpose) just SE of Tucson. As strange as it may look, this "window," despite its meager size, characterizes the actual features of this plain drained by the Santa Cruz River.

A cross section through the floor of the wide valley shows an upper mantle of gravel, overlying the loamy alluvial formations which can be clearly seen through the so called "window," recognisable because numerous gullies have "chiselled" and carved tremendous sculptures through the upper mantle. Just beneath this blanket, one recognizes an old A_1 horizon, rich in organic matter, still intact, only buried beneath these gravels (see Figure 10). The water is stored within the loamy formation. At night, the moisture, when moving upward, reaches the top of this paleosoil, but not the surface of the ground which looks cooler than it should with respect to its altimetric position, despite the indubitable presence of humidity some cemtimeters below (at a pinch, 1 or 2 meters). This quasi-permanent humidity explains the success of several Indian settlements, of the newly created extension of the city of Tucson, Green Valley, and the growing farming activities.

Figure 10—Plain south of Tucson, drained by the Santa Cruz River (gulley erosion; the dashed line depicts the horizon A of a buried soil).

Former Hydrography (Figure 7)

The reconstruction proposed in Figure 7 fits not only the pattern of the distribution of T_{BB}, but also the topographical features observed in the field, such as prolongation of valleys, spurs, and alluvial deposits. It must be said that such conclusions could have been reached without the help of the Nimbus II measurements, but when? Actually, I had already suggested the possibility of a former course for the Amargosa River in 1965 (Reference 2) and again in 1967 (Reference 1). Identical suppositions have been made by numerous colleagues, and the tourists in Death Valley can observe a map at the Information Center of Furnace Creek Ranch giving the same information about a former link between Death Valley and the Colorado River.

The reconstruction of the former hydrographic patterns, perhaps the one that existed during and after the last glacial stage, is rendered especially difficult because of the tectonic movements that have since taken place and are still active in numerous places. For example, the existence of a link between the Amargosa River and the region of Amboy Lake is generally agreed. Personally, I stopped this former route at Amboy, but I would not oppose my colleagues who prolonged it until the Colorado. It is supposed that the former river (Amargosa) was truncated by the formation of the Amboy volcano which occurred in a recent past.

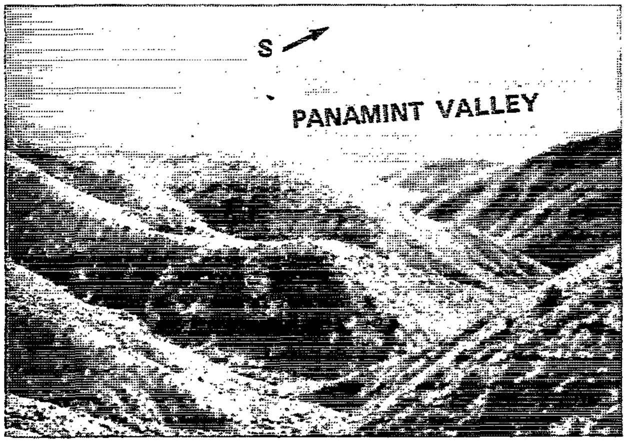


Figure 11—Link between Saline and Panamint Valley. (Background: Panamint Valley; foreground: spurs are what is left of the floor of a former valley.)

Saline Valley and Panamint Valley have been linked by a river whose traces are still perfectly discernible with the spurs and alluvial deposits (see Figure 11), but without any influence upon the distribution of the equivalent black-body temperatures because of the resolution of the radiometer. Death Valley was drained southward, and the river which was the effluent of the well-known Manly Lake was an affluent of the Amargosa River (to-day the Amargosa empties in Death Valley).

Two centers of attraction existed, perhaps simultaneously, perhaps at different periods. One is located between Vidal Junction and Desert Center, as is easily seen on the equivalent black-body temperature maps. Still today, when walking along these dry valleys, it is not difficult to imagine the impetuous streams that once, but not so long ago, drained these areas.

The second center is the depression of Coachella Basin toward which the former Colorados (I insist on the plural) used to flow. But, I do not know whether the former Colorado ever reached the basin or not, because the map of the T_{BB} shows a break: these strips of warmer areas do not reach the collapsed basin, and there are no clues, on the field, about a former situation.

The hydrographic patterns established at the time of the last glaciation, about 12,000 years ago, have been disrupted by the tectonic activities. The Amargosa River had to abandon its course, being diverted by the sudden collapse of Death Valley. When Saline Valley collapsed, possibly later than Death Valley, the link was broken with Panamint Valley and two different physiographic units came into existence. The link between Panamint Valley and Death Valley was broken in the same way. Furthermore, the remaining part of the Amargosa River was cut in its turn by the volcanic activity of Amboy.

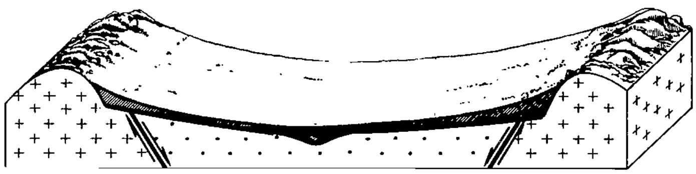
I suppose that the Colorado River originally reached the region of the Salton Sea. Then tectonic movement broke the link forcing the river to move southward. At the beginning of the century, because of man's activities, the Colorado flowed toward the trough known at that time as Salton *Sink,* filling the basin now known as the Salton *Sea*. Man forced the river to return to the Gulf of California. It is my belief that, even without human intervention, the Colorado would have emptied into the Coachella Basin, because recent movements lowered the graben a little more.

Types of Valleys (Figure 12)

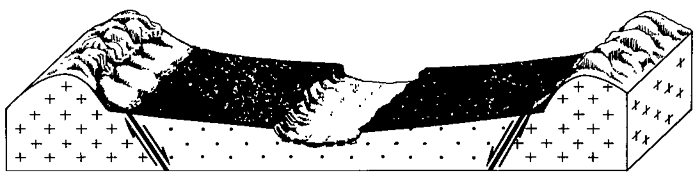
The word valley is used with a broad meaning, affixed to elongated depressions that were formerly drained. All owe their existence to tectonic factors, i.e., creation of collapsed troughs while the borders were moving upward, relatively speaking. The streams "rounded" the angles, giving a general shape in accordance with the normal fluvial valleys. With the passing of time, an equilibrium was realized, and the rivers filled their valley with alluvial deposits whose thickness is related to the depth of the tectonic basins and to the strength of the streams; the Colorado (being the more powerful) has left the deepest and widest alluviums. At a given time, all of these valleys looked as shown in Figure 12A (also Figure 13).

Then the tectonic movements recurred but, as usual, not at the same places nor with the same strength. Some areas were not affected, as Vidal Valley, Indian Springs Valley (North of Las Vegas);

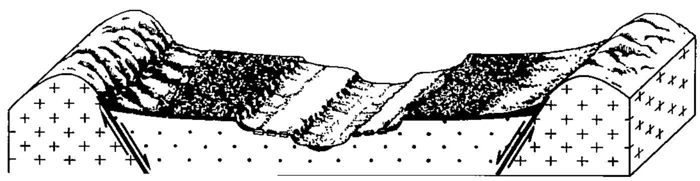
a. VIDAL VALLEY TYPE-GREATEST POSSIBILITIES OF WATER STORAGE (TECTONIC STABILITY)



b. NEEDLES VALLEY TYPE-REDUCED BUT TANGIBLE POSSIBILITIES OF WATER STORAGE (RELATIVELY WEAK TECTONIC ACTIVITY)



c. DEATH VALLEY TYPE-NO MORE POSSIBILITIES OF WATER STORAGE (VIOLENT TECTONIC EXASPERATION)



BED ROCKS

COARSE DEPOSITS AND LAKE DEPOSITS (INCLUDING FORMER LAKE FANS AND APRONS)

FINE GRAINED DEPOSITS ('PLAYAS')

PEDIMENTS WITH DESERTIC PAVEMENT (DARK COATING OF THE PEBBLES)

PEDIMENTS WITH DESERTIC PAVEMENT (LIGHT COLORED COATING)

SUPERFICIAL DEPOSITS' COLLUVIAL AND SEMI-FLUVIAL ORIGIN

FAULTS

Figure 12—Schematic categories of "valleys" in Southwest United States.

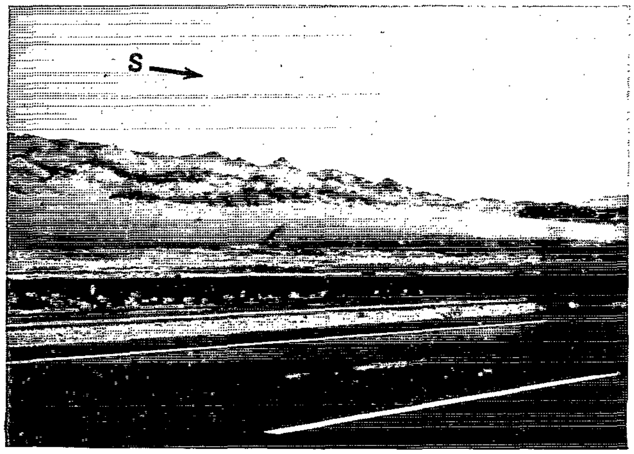


Figure 13—Indian Springs Valley (Nevada) type "a" of Figure 12. (The apron reaches a high level against the mountain ridge. Undisturbed alluvial deposits able to retain the humidity provided by rain, dew, underground water, etc.)

some others were slightly disturbed, as the southern part of Death Valley, Panamint Valley.

Finally, as is the case with the most striking examples of the median part of Death Valley and Saline Valley, the tectonic movements were so strong and also so recent (they are still acting) that only a few remnants of the former landscapes are seen here and there.

In Figure 7, the areas warmer than they should be are individualized with the symbol + and the letters R or W. R stands for Rock formation, while W evokes the influence of water (humidity, moisture). Curiously, the field work has shown the symbol + with the letter W to coincide with the categories A and B of Figure 9. In other words, when rejuvenation of erosion is strong enough (category c of Figure 9), the alluvial deposits, being "wounded" too deeply, are unable to store the humidity regardless of the origin of the water.

CONCLUSION

The former statement is given not as a formal conclusion but as a sound basis for further investigations, in the same region and elsewhere. Let me repeat once more that the preceding conclusions might have been reached without the help of the satellite measurements but with numerous specialists, and many, many years of field work.

Looking backward, the principal results belong to the field, not of pure geomorphology but rather, of the Earth's Resources investigations in the arid and sub-arid lands. I have never said that water has been discovered through the study of the equivalent black-body temperature patterns, or that water might be found that way. Everybody knows that the power of penetration of the infrared radiations is close to zero (around 2 or 3μ); in consequence, it is not possible to see beneath the very surface of the ground. But, for trained specialists, the deductive way of reasoning allows one to reconstruct with accuracy what exists beneath that surface, exactly as we reconstruct a syncline without actually seeing it.

Once more, as final words, I must repeat what I wrote at the beginning: a confirmed specialist in geology, geomorphology, geopedology, with a strong background in his discipline, can save a substantial amount of time when the satellite measurements are available.

ACKNOWLEDGMENTS

Because this study is the last I shall be able to achieve while at NASA's Goddard Space Flight Center, I wish to emphasize my deep gratitude to all the colleagues who have helped me during my investigations, especially, in alphabetical order, Messrs. Allison (Lew); Bandeen, Head of the Planetary Radiations Branch; Conaway (Jack); Goldberg; Hovis; Kreins; McCulloch; McMillin; Nordberg, Asst. Chief of the Laboratory for Atmospheric and Biological Sciences; Raschke, NAS fellow; Warnecke, NAS fellow; Williamson (Jim), NAS fellow; and many others whose names I do not recall. Perhaps they do not understand why I am thanking them, but through conversation I learned from all of them what I consider the necessary background of a new tool to be used by the oldest of the sciences.

My research would have been quite impossible without the help of the National Academy of Sciences, Science Research Council which provided the facilities for my sojourn at NASA's Goddard Space Flight Center where I must recognize I spent one of the most enjoyable years of my life. Mr. John Sharsmith, ranger at the National Monument of Death Valley, deserves a special mention. While "on the field," in Saline Valley, he has been of the greatest help, because, as I told him, he has the "geologic eye": many many times he attracted my attention to various features I might otherwise have overlooked.

Goddard Space Flight Center
National Aeronautics and Space Administration
Greenbelt, Maryland, April 22, 1968
160-44-03-35-51

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